LEVEL II

3

AD A098122

ARVIN/CALSPAN

ADVANCED TECHNOLOGY CENTER

DTIC
ELECTE
APR 23 1981
S D
E

DTIC FILE COPY

[illegible] BUFFALO, NEW YORK [illegible]

THE TECHNOLOGY GROUP OF ARVIN INDUSTRIES INC

ATG
ARVIN

81 4 22 060

AFOSR-TR- 81-0399

LEVEL II

3

CALSPAN ADVANCED TECHNOLOGY CENTER

BOUNDARY LAYER TRANSITION AND SURFACE ROUGHNESS EFFECTS IN HYPERSONIC FLOW

ANNUAL TECHNICAL REPORT

Calspan Report No. 6430-A-1

February 1981

DTIC

Prepared for:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AIR FORCE BASE, DC 20332

CONTRACT NO. F49620-79-C-0003
1 NOVEMBER 1979 - 1 NOVEMBER 1980

Principal Investigator: Michael S. Holden
Telephone No. (716) 632-7500
-6853
Aerodynamic Research Department
Advanced Technology Center

A DIVISION OF CALSPAN CORPORATION

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR-81-0399	2. GOVT ACCESSION NO. AD-A098 122	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BOUNDARY LAYER TRANSITION AND SURFACE ROUGHNESS EFFECTS IN HYPERSONIC FLOW		5. TYPE OF REPORT & PERIOD COVERED Annual rept. 1 Nov 1979 - 1 Nov 1980
		6. PERFORMING ORG. REPORT NUMBER CALSPAN-6430-A-1
7. AUTHOR(s) Michael S. Holden		8. CONTRACT OR GRANT NUMBER(s) F49620-79-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS Calspan Advanced Technology Center P. O. Box 400, Buffalo, NY 14225		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2307/A1
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research Bolling Air Force Base, D.C. 20332		12. REPORT DATE February 1981
		13. NUMBER OF PAGES 37
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 46		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hypersonic Flow	Stagnation Point Heating	Ballistic
Turbulent Boundary Layers	Ablated Nose Shape	Maneuverable
Surface Roughness	Heat Transfer	Re-entry
Boundary Layer Transition	Skin Friction	Entropy Swallowing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experimental studies are being conducted to examine the stagnation region heating in transitional flow over blunt nose tips; and the effects of surface roughness on the heat transfer and skin friction to hypersonic re-entry vehicles.

Measurements have been made of the distribution of heat transfer and skin friction over sharp and blunted cones to a range of incidences for surface roughness of 0, 10 and 15 mils. These studies have been conducted at a local

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

410 803

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued

Mach number of 11.7 and Reynolds numbers based on model length of ~~30×10^6,~~ giving roughness Reynolds numbers from transitional to fully rough over the models. New calorimeter and thin film instrumentation was developed expressly for the rough wall heating measurements. The measurements indicated that while the roughness-induced augmentations in heat transfer and skin friction were less than would be predicted using theories based on low speed data for low R_k's, close to the nose tip significantly larger augmentation factors were observed. The current studies suggest that significant compressibility effects may be present in hypersonic turbulent boundary layers over rough walls.

The models and highly detailed heat transfer and pressure instrumentation have been completed for the stagnation point heating studies. A new and novel throat valve has been developed to eliminate the frangible mylar diaphragm which can cause particles and disturbances during flow establishment in the shock tunnel. The experimental studies are now in progress.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

Section 1
INTRODUCTION

In this program we are addressing two aerothermal problems which are of fundamental importance in the design of high speed re-entry vehicles. The first of these problems is associated with the heating augmentation which is believed to occur in the stagnation region of a blunt body for transitional flow over the nose tip. The second problem is the effects of surface topography and compressibility on heating to rough surfaces in hypersonic flow. During the past year we have worked on these problems simultaneously, and detailed experimental programs are now underway in both areas.

Section 2
STUDIES OF STAGNATION REGION HEATING

Based on conventional theoretical studies, the heat transfer at the stagnation point of a blunt body should be equal to the laminar value, even if transition moves close to the stagnation point. However, recession measurements in the stagnation region of ballistic re-entry vehicles and heat transfer measurements in wind tunnels and ballistic ranges suggest that stagnation point heat transfer rates increase as transition approaches the stagnation region, as indicated in Figure 1. The tunnel measurements shown here were made over a range of Reynolds numbers, such that the smallest values of S_{tr}/D correspond to the largest unit Reynolds number. It could be argued that increased tunnel noise causes the increased heating; however, since ballistic range measurements also exhibit this effect in the absence of tunnel noise, potential noise effects are clearly not the sole cause of enhanced heating. Current codes which are used to predict the performance of ablative nose tips must incorporate a semi-empirical relationship to significantly enhance the stagnation point heating above the laminar value. On the basis of the data shown in Figure 1, a basic aerothermal phenomenon remains to be understood. Because the flow in the stagnation region is subsonic, it is clear that the pressure disturbances generated by transition can feed upstream; however, whether these disturbances are of sufficient magnitude to induce large heating augmentation remains to be determined.

In the present experimental studies, we are using a hemispherical nose tip heavily instrumented in the stagnation region with high frequency heat transfer and pressure gages. A drawing of the model is shown in Figure 2 and photographs of the completed model showing the placement of the instrumentation are given in Figure 3. Heat transfer gages have been positioned along a major axis through the stagnation region to detect the mean and fluctuating components of the flow. On a second major axis, pairs of thin-film gages and high frequency Kulite pressure gages have been positioned so that the forward movement of transition can be detected and fluctuations in

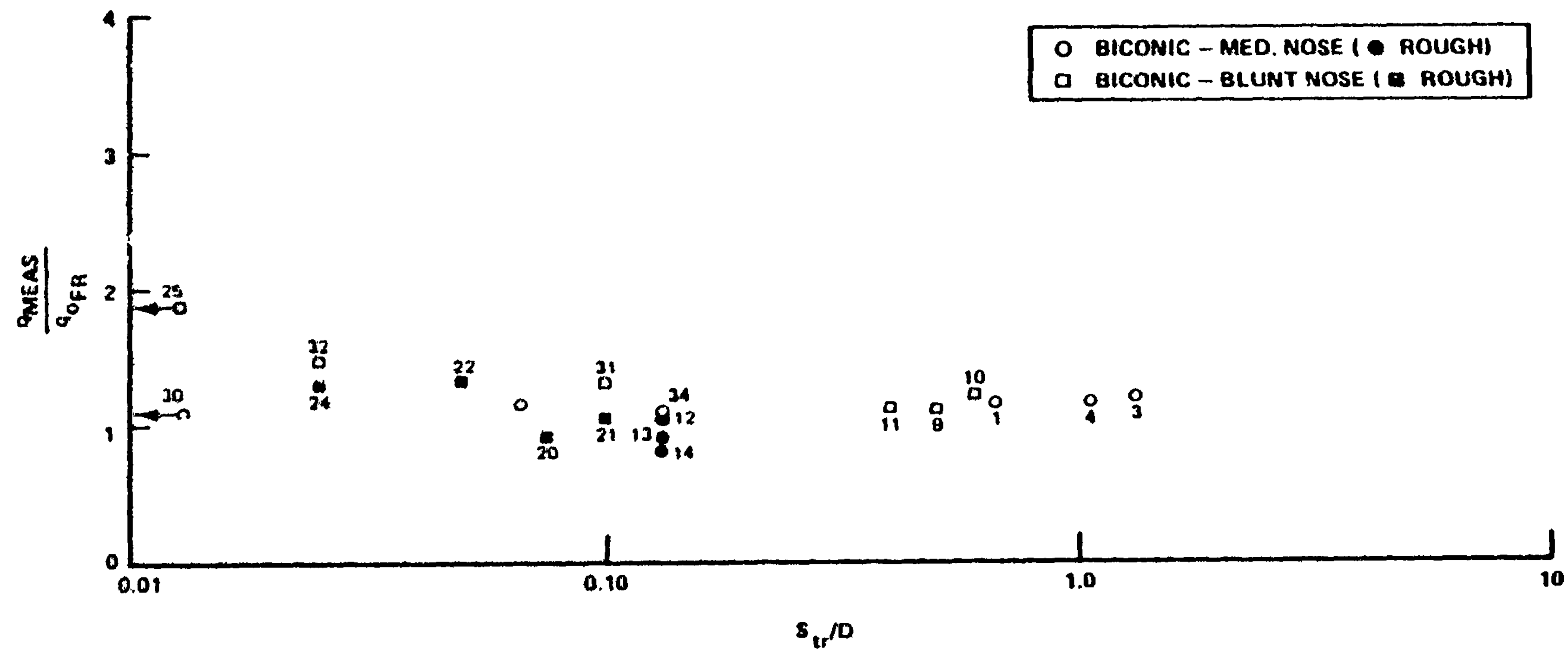
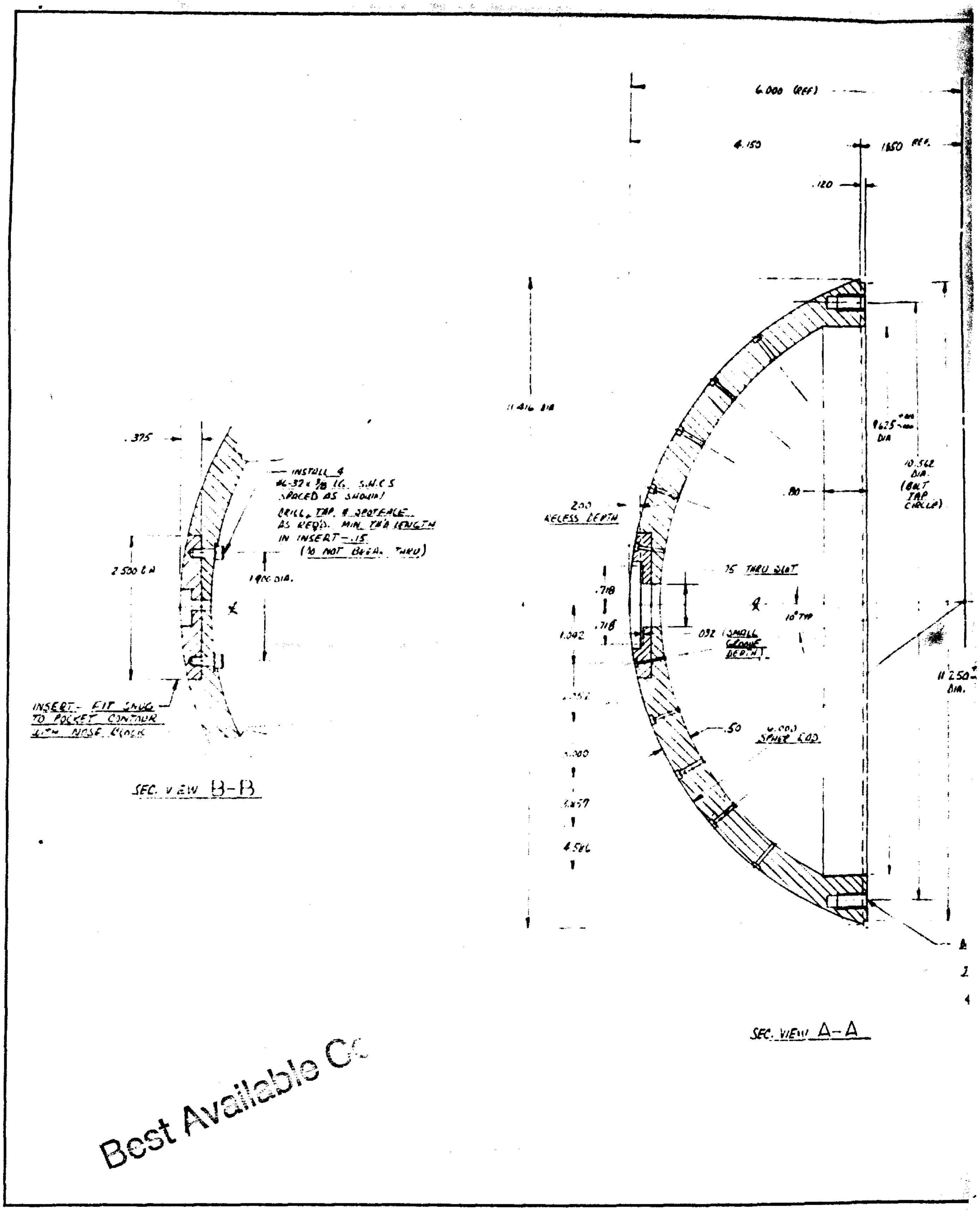


Figure 1 VARIATION OF STAGNATION POINT HEATING WITH DISTANCE OF THE TRANSITION POINT FROM THE STAGNATION POINT


6.000 (REF)
4.150
1.850 REF.
.120
11.416 DIA
.375
INSTALL 4
#6-32 x 3/8 LG. S.H.C.S
SPACED AS SHOWN
DRILL, TAP, & SPOTFACE
AS REQD. MIN. THD LENGTH
IN INSERT - .15
(DO NOT BREAK THRU)
2.500
1.900 DIA.
INSERT - FIT SNUG
TO POCKET CONTOUR
WITH NOSE BLOCK
SEC. VIEW B-B
.200
RECESS DEPTH
.80
10.562
DIA.
(BOLT
TAP
CIRCLE)
.718
.718
1.042
.25 THRU SLOT
10° TYP
.032 (SMALL
GROOVE
DEPTH)
.50
11.250
DIA.
SEC. VIEW A-A

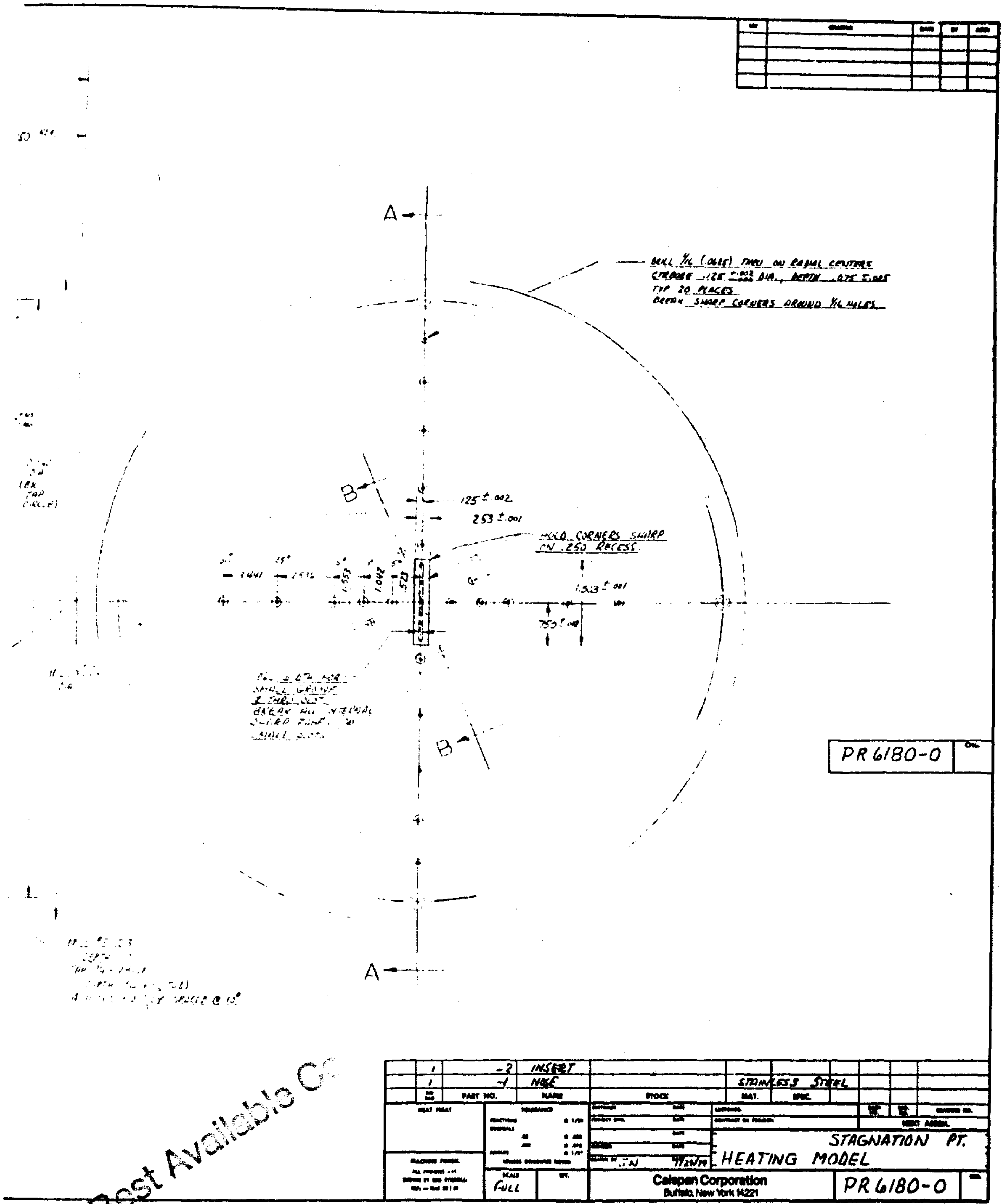
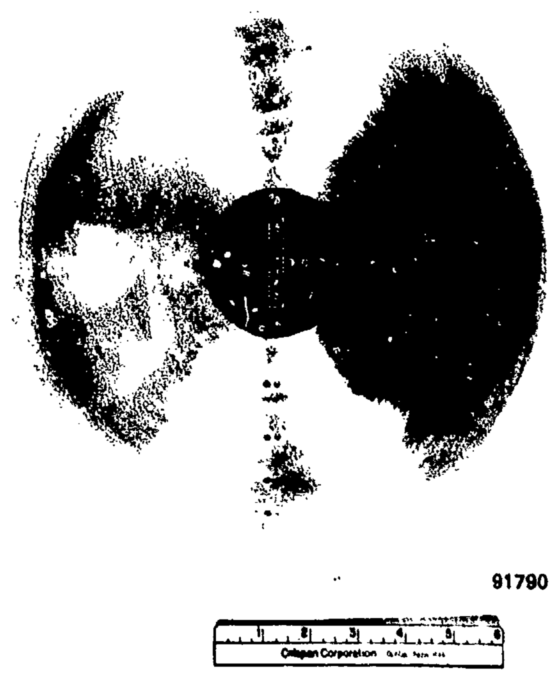


Figure 2 STAGNATION POINT HEATING MODEL

91789

(a)



91790

(b)

Figure 3 HEMISPHERE MODEL FOR SCANT REFERENCE STUDIES

pressure and heat transfer measured. From these measurements, we hope to determine the nature and magnitude of the upstream influence through the shock layer in this stagnation region.

To position the point of transition around the hemisphere, we will vary both the unit Reynolds number of the free stream and the positions of axisymmetric annular trip rings. In the latter studies, we will eliminate the effects of changes in tunnel noise on the stagnation point heating rate and also bring transition very close to the stagnation region. A preliminary matrix for these experimental studies is shown in Figure 4. The initial studies will be conducted at Reynolds numbers of 1×10^6 through 11×10^6 to examine the variation in the position of transition and the stagnation point heating with this parameter. We will then examine the effects of trip height and position on transition and stagnation point heating. The measurements of the fluctuating components of heat transfer and pressure will be recorded on a high frequency (5 MHz) biomation digital recorder as will the fluctuations in the pitot pressure and the cooled-film probe positions in the test section rake.

As part of our ongoing internal research efforts aimed at facility and diagnostic development we embarked on an extensive internal research program to examine and then eliminate any aerothermal effects which might influence the results or cause inaccuracies in stagnation heating rates. Since our detailed studies of particle - shock layer interaction, we have been acutely aware of the large effects even the smallest particles can create in the stagnation of blunt bodies at hypersonic speed. These studies demonstrated that the disturbances induced in the shock layer of a blunt body by small particles can cause significant increases in heating, and these disturbances can persist in the stagnation region for some time. In the conventional operational of our shock tunnel, we employ thin mylar diaphragms to contain the driven tube pressure. This mylar is broken by the incident shock when the tunnel is fired, and tiny particles may be swept onto and past the model during flow establishment over the model. It is the flow disturbances introduced by the mylar during the start process of the tunnel

RUN	CONFIGURATION	M_∞	Re_∞	k (mils)	COMMENTS
1	SMOOTH HEMISPHERE	11	11×10^6	0	REFERENCE DATA FOR SCANT
2	SMOOTH HEMISPHERE	11	4.1×10^6	0	REFERENCE DATA FOR SCANT
3	SMOOTH HEMISPHERE	11	1×10^6	0	REFERENCE DATA FOR SCANT
4	HEMISPHERE WITH ANNULAR TRIP	11	$Re_1 \times 10^6$	10	$\theta_{TRIP} = \theta_1$
5	HEMISPHERE WITH ANNULAR TRIP	11	$Re_1 \times 10^6$	15	$\theta_{TRIP} = \theta_1$
6	HEMISPHERE WITH ANNULAR TRIP	11	$Re_1 \times 10^6$	k_1	$\theta_{TRIP} = \theta_2$
7	HEMISPHERE WITH ANNULAR TRIP	11	$Re_1 \times 10^6$	k_1	$\theta_{TRIP} = \theta_3$
8	HEMISPHERE WITH ANNULAR TRIP	11	$Re_2 \times 10^6$	–	$\theta_{TRIP} = \theta_3$
9	HEMISPHERE WTIH ANNULAR TRIP	11	$Re_2 \times 10^6$	10	$\theta_{TRIP} = \theta_4$
10	HEMISPHERE WITH ANNULAR TRIP	11	$Re_3 \times 10^6$	–	–

Figure 4   STAGNATION POINT HEATING AND SCANT REFERENCE STUDIES

that might under some circumstances persist into the steady run time, causing fluctuations in the stagnation regions which would complicate our studies. Therefore, prior to the experimental studies, a renewed effort was undertaken to complete the development of a throat valve to replace the mylar.

Over the years, many concepts have been considered to replace the throat mylar; however, the dual requirements of fast action and the strength to retain forces of over 60,000 lbs if the system malfunctioned, eliminated after extensive studies, devices like hydraulically or mechanically driven ball or gate valves. A major design problem associated with the use of such devices is that if they do not open, both the valve and the tunnel structure are required to perform without incurring structural damage. To eliminate this feature, we decided to make the sealing member expendable; however, we were left with the problem of how to keep the model from being damaged. At this time, we observed mylar sheet could be used to seal an orifice without a clamping force being applied if the size of the mylar sheet was at least twice the orifice size and if it were closely contained within a slot. In case of system failure, the mylar would be partly burned, blown apart and be convected down the nozzle in the usual way. Since a mylar diaphragm of sufficient strength to restrain the driven tube pressure is very light, it can be pulled rapidly (< 2 ms) from the throat. We chose to use the mechanism shown in Figure 5 for the extraction of the mylar sheet. In this arrangement, we pull the mylar from the orifice by driving a piston into the mylar sheet which is fastened such that the mylar is pushed into the cavity in front of the piston. To actuate the piston, a high pressure source is exposed to the back face of the piston through a fast-acting Valcor valve. This valve is triggered by pulses from instrumentation placed in the driven tube close to the double diaphragm system. This new throat valve has been designed, constructed and tested under internal research to provide a far cleaner tunnel starting process, which we believe will improve the studies of flows over blunt bodies. In addition to the new Biomation recorders and throat valve, we will also employ a new TSI cooled-film anemometer system to measure the

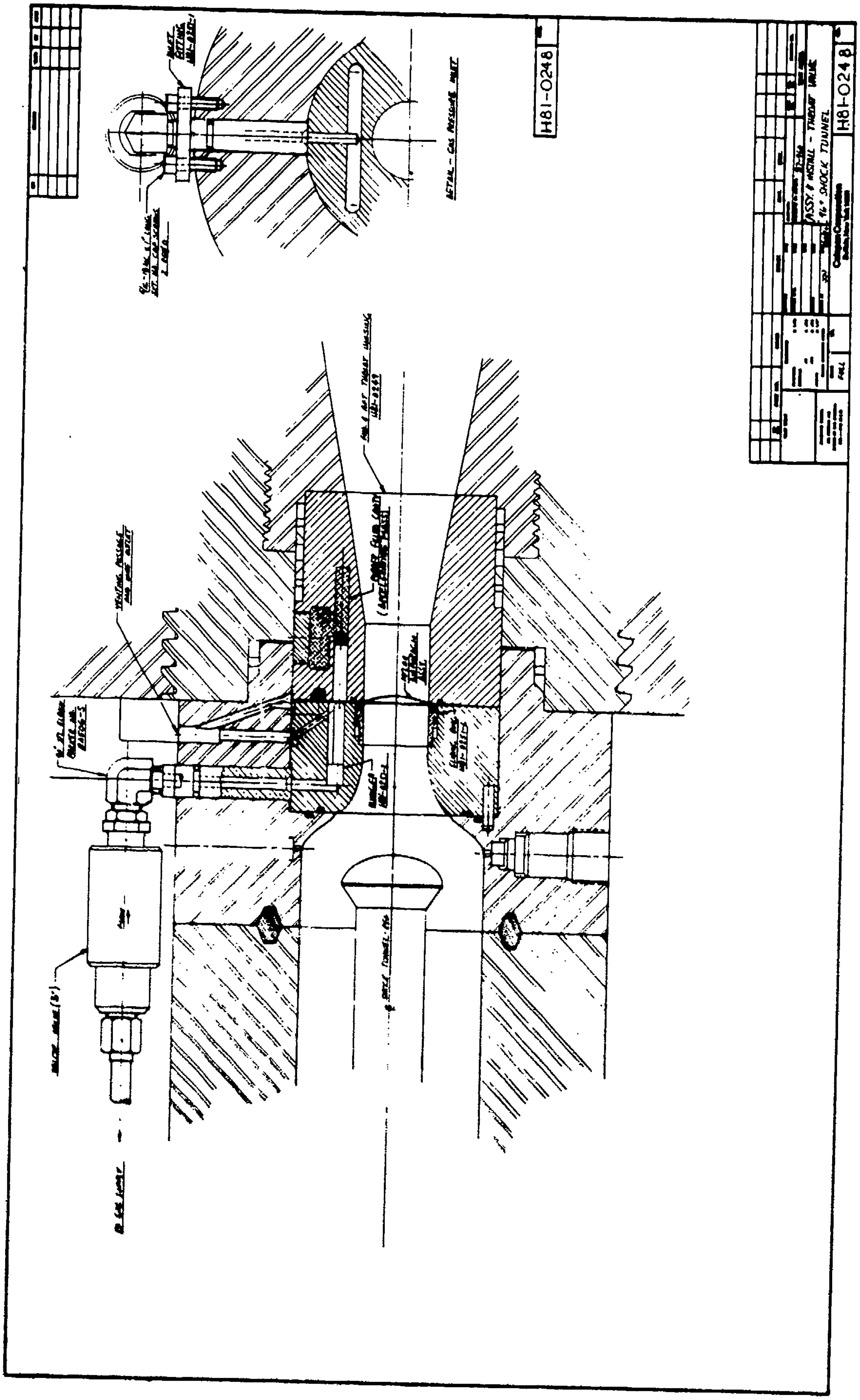


Figure 5 NEW THROAT VALVE

fluctuation levels of the free stream. The experimental program to study stagnation point heating will be conducted during March.

Section 3
SURFACE ROUGHNESS EFFECTS IN HYPERSONIC FLOWS

During the current reporting period, we have been conducting experimental studies to examine the effects of surface roughness on the heating and skin friction to sharp and blunted cones in hypersonic flows. The analysis of our earlier studies indicated that the character and spacing of the surface roughness elements, and not just the roughness height, were of key importance in influencing the surface heating and skin friction. We therefore embarked on a program to (i) improve the accuracy with which we could replicate a particular surface topography on the surface of heat transfer gages, and (ii) develop calorimeter type heat transfer gages for the direct measurement of substrate heating.

3.1 Model and Instrumentation

The experimental program was conducted in Calspan's 96-inch shock tunnel at Mach numbers from 11 to 15 and Reynolds numbers up to 30×10^6. Two basic model configurations were employed in this study: the conical and biconic configurations shown in Figures 6 and 7. Figure 8 shows details of the highly instrumented flap section of the model which contained thin film and calorimeter heat transfer gages, skin friction gages and flush mounted pressure transducers. Smooth, 10 mil and 15 mil rough surfaces and instrumentation were employed in these studies. We employed both thin film and calorimeter instrumentation to determine the heat transfer rates to the rough surfaces.

The thin film "S" gage shown in Figure 9 is a new instrument developed specifically for measurements of rough wall heating. The sensitive element is a platinum film that is sputtered uniformly onto a glass substrate which is molded into the surface topography of sand grain roughness. The steps taken in the construction of these gages are depicted in Figure 10. A ceramic mold is made of the surface to be duplicated and the glass substrate

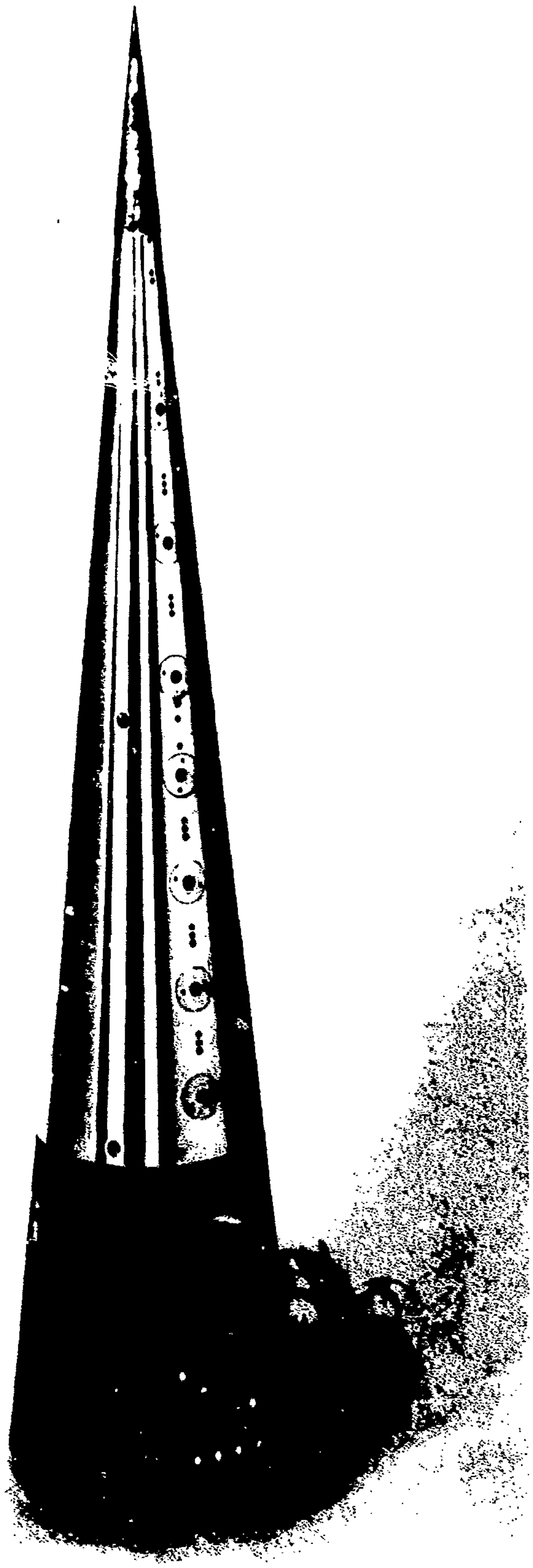


Figure 6 CONICAL MRV CONFIGURATION

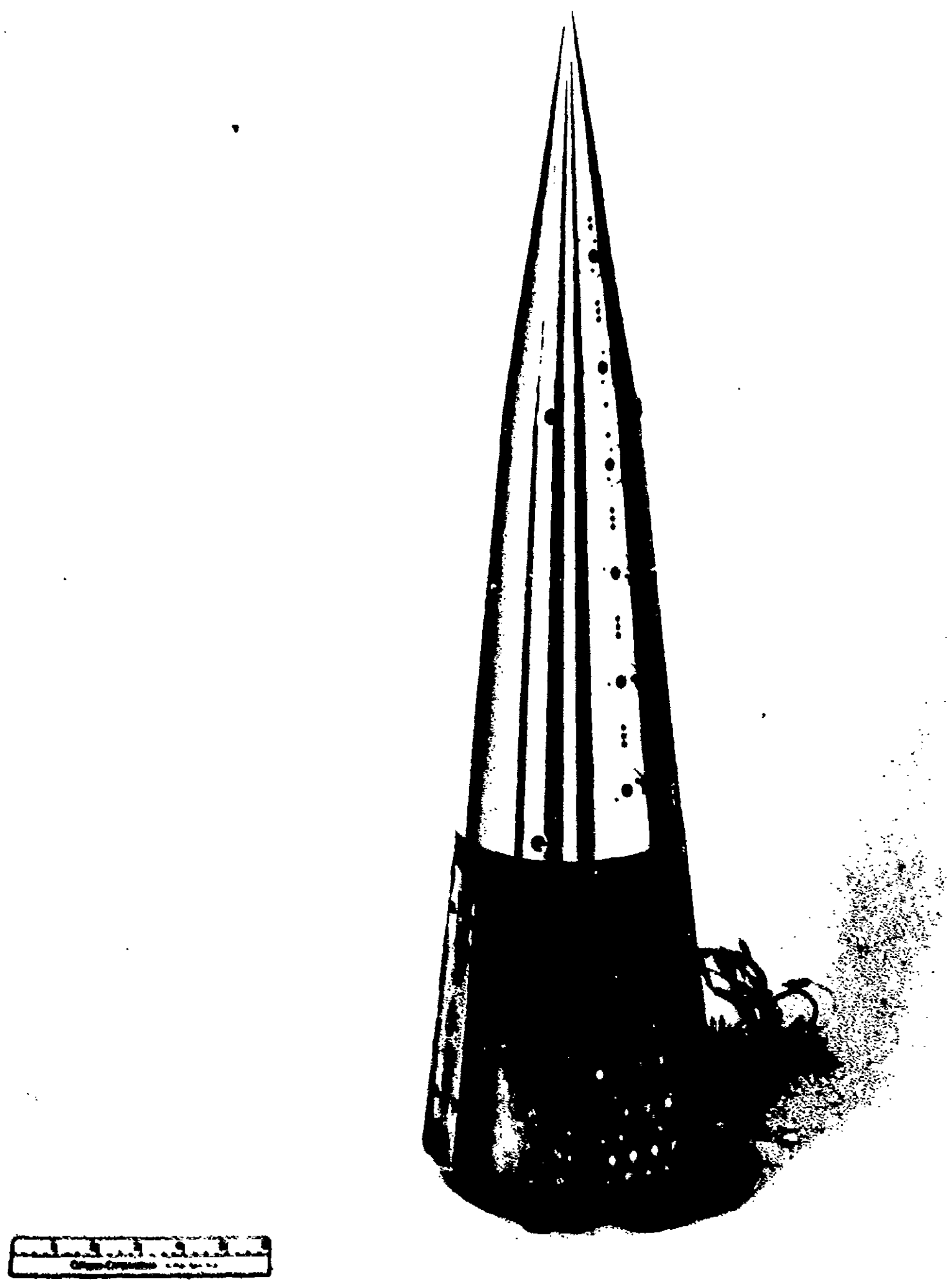


Figure 7 BICONIC MRV CONFIGURATION

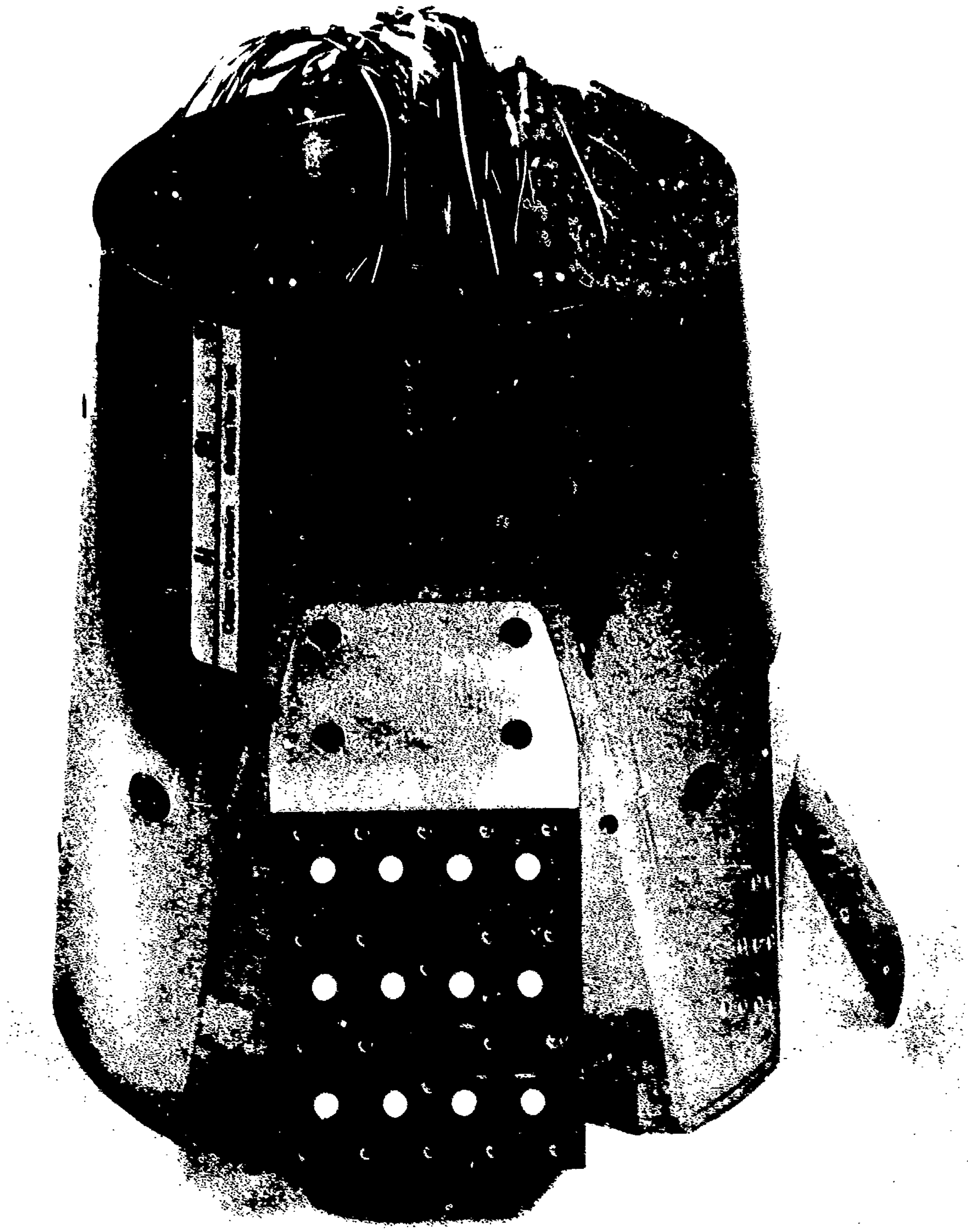


Figure 8 INSTRUMENTATED FLAP SECTION OF MRV

Figure 9 MASK AND ROUGH AND SMOOTH THIN FILM "S" GAGES

Figure 10 SEQUENCE OF CONSTRUCTION OF NEW ROUGH "S" THIN FILM GAGES

is then molded, under heat and pressure, into the shape of the roughness. After preparatory coatings are deposited on the glass, platinum film is sputtered onto the surface through a collimating mask (shown in Figure 8), which has an "S" aperture to achieve the maximum possible platinum coverage over the surface. The output of the gage is a function of the average heat transfer rate to the surface of the gage. If the heating rate through a plane in the substrate parallel to the average surface (which is the conventional way of presenting rough wall data) is required, the measured heating rate must be multiplied by the ratio A_s/A_p, where A_s is the surface area of the gage and A_p is the projected area. This ratio can be determined using the radiant source calibrator shown in Figure 11.

The rough calorimeter gage shown in Figure 12 is the second gage developed at Calspan specifically for accurate measurements of rough wall heating in hypersonic flow. Substrate heating can be determined directly from the gage output by employing an isolated calorimeter element whose thermal properties and mass can be accurately specified, and a temperature sensing element that is accurately calibrated, to remove the inaccuracies associated with calibration using a radiant source. The gage construction is depicted in the sectional diagram shown in Figure 13. A silver calorimeter element is bonded to a ceramic holder using an extremely low conductivity polyurethane. The temperature of the disc is sensed with a thin-film (see Figure 13). Evaluation and calibration studies with the CO laser calibrator shown in Figure 14 demonstrated that the gage had a response time of less than 800 μs and could be used to resolve heating rates down to 5 Btu/ft^2 sec. Direct comparisons between heat transfer measurements using thin-film and calorimeter gages on smooth conical configurations (one of which is shown in Figure 14) has demonstrated that the calorimeter gages have an accuracy close to the 5% level associated with the well-tested platinum thin-film gage. The rough calorimeter elements are molded using a technique similar to that employed to construct the pyrex buttons of the thin-film gages shown in Figure 15, but in this case, molten silver is poured into the ceramic mold. After the button is cut from the rough silver impression, profilometer measurements are made to select the roughness characteristic required. The

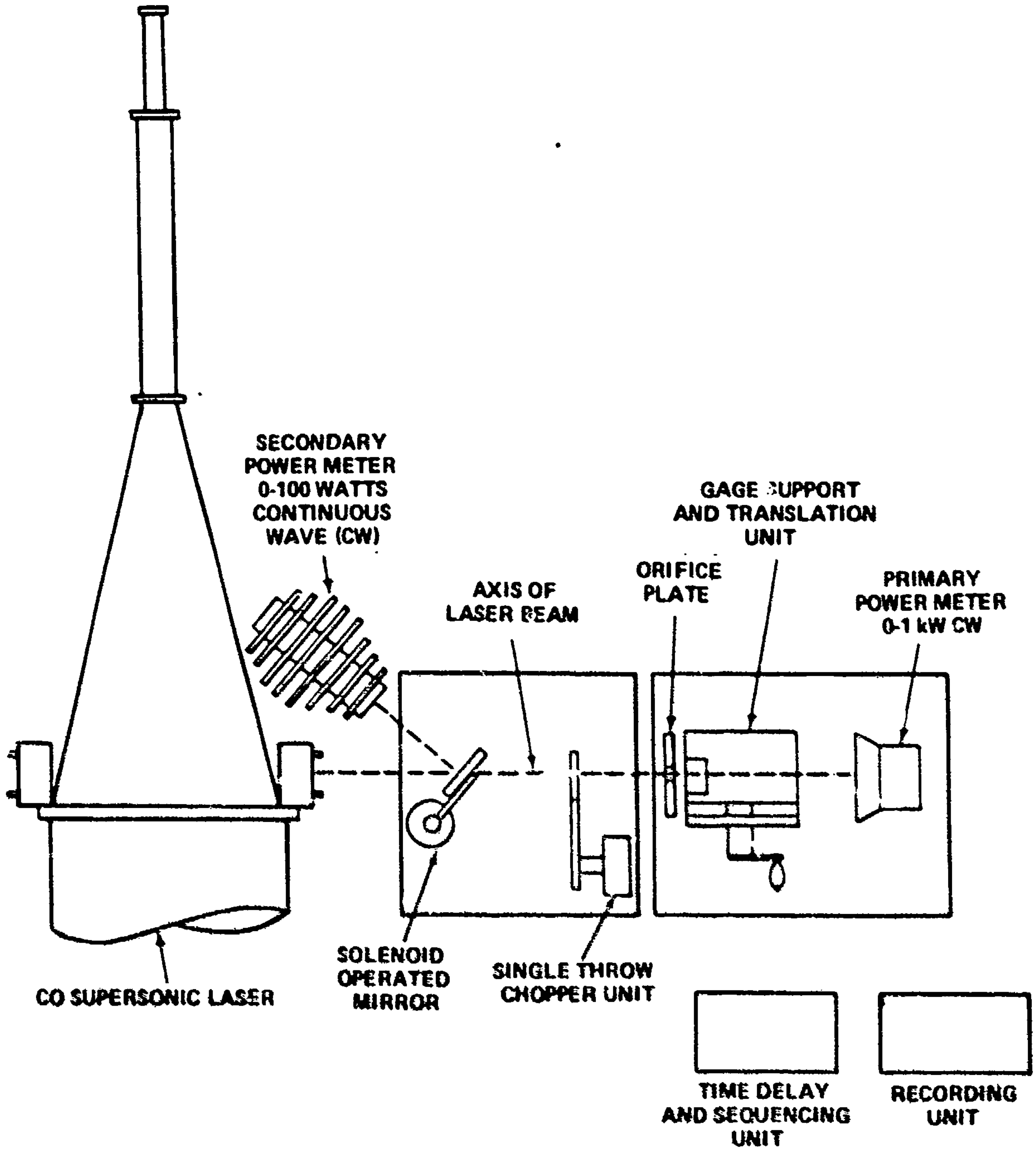


Figure 11 SCHEMATIC OF HIGH FLUX HEAT CALIBRATOR

(a) SILVER CALORIMETER GAGE

(b) THIN FILM "S" GAGE

Figure 12 ROUGH HEAT TRANSFER GAGES USED IN THE CURRENT STUDIES

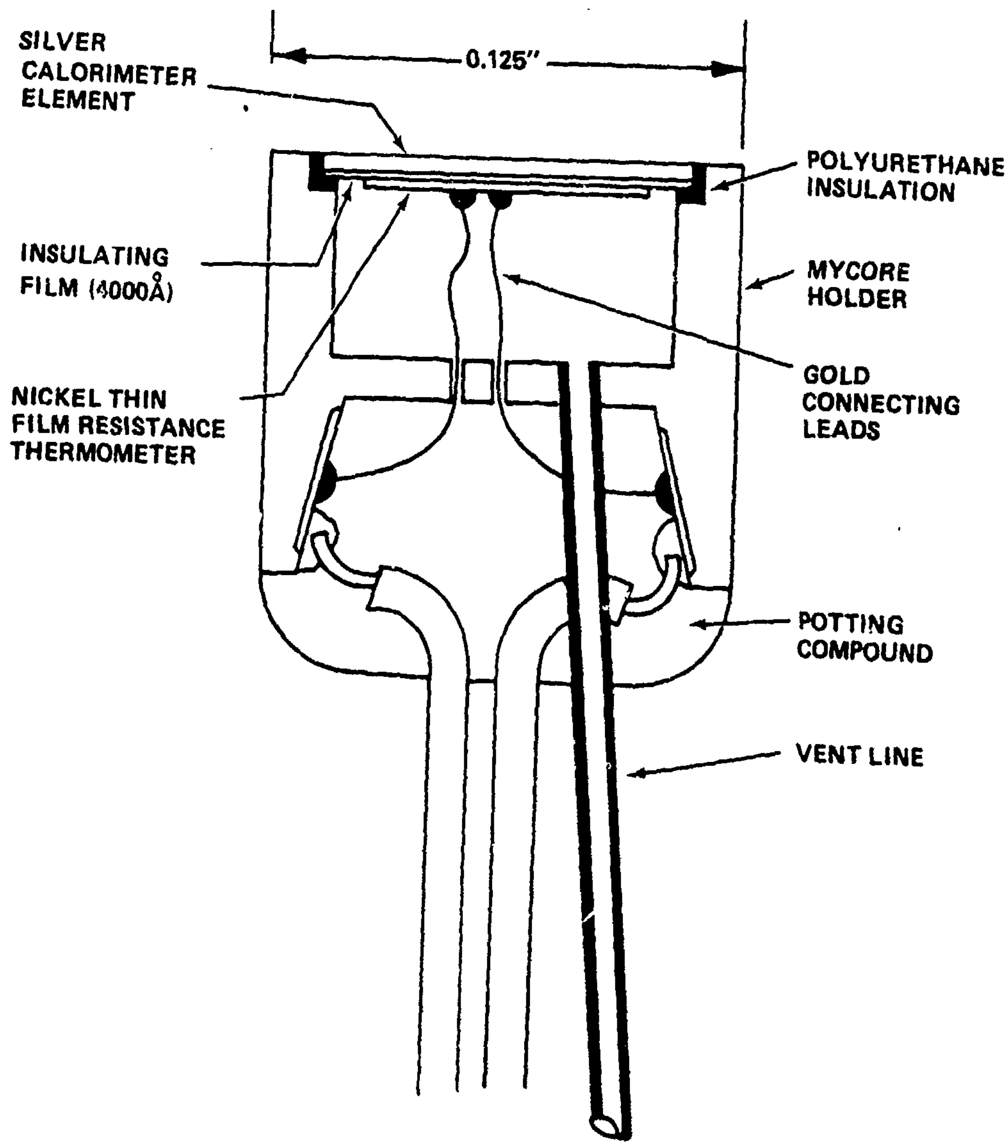
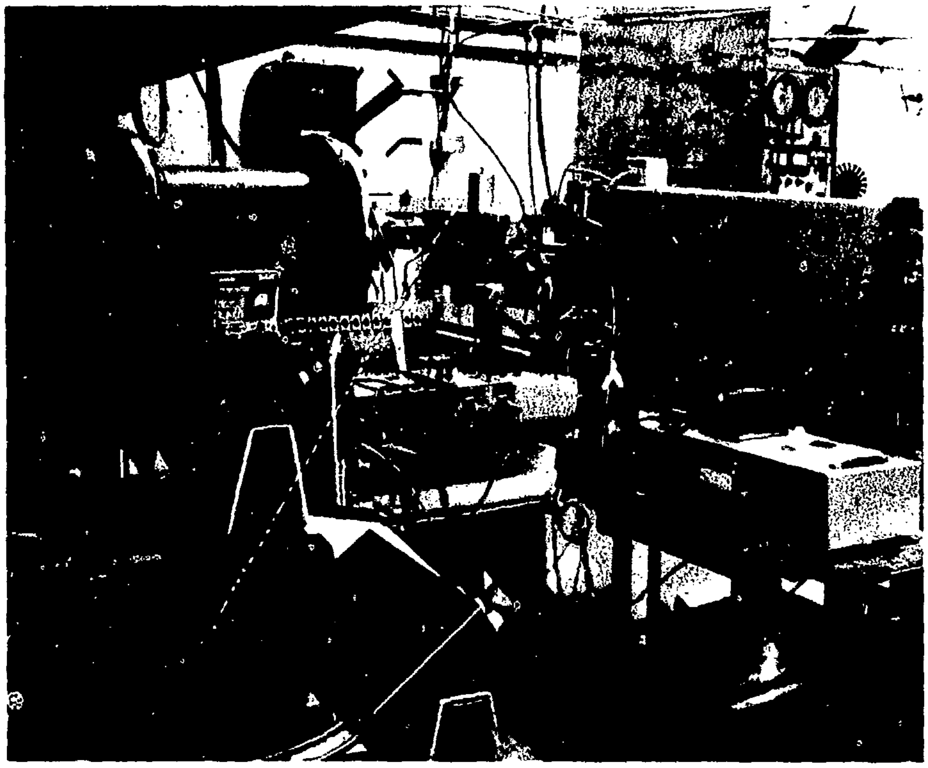
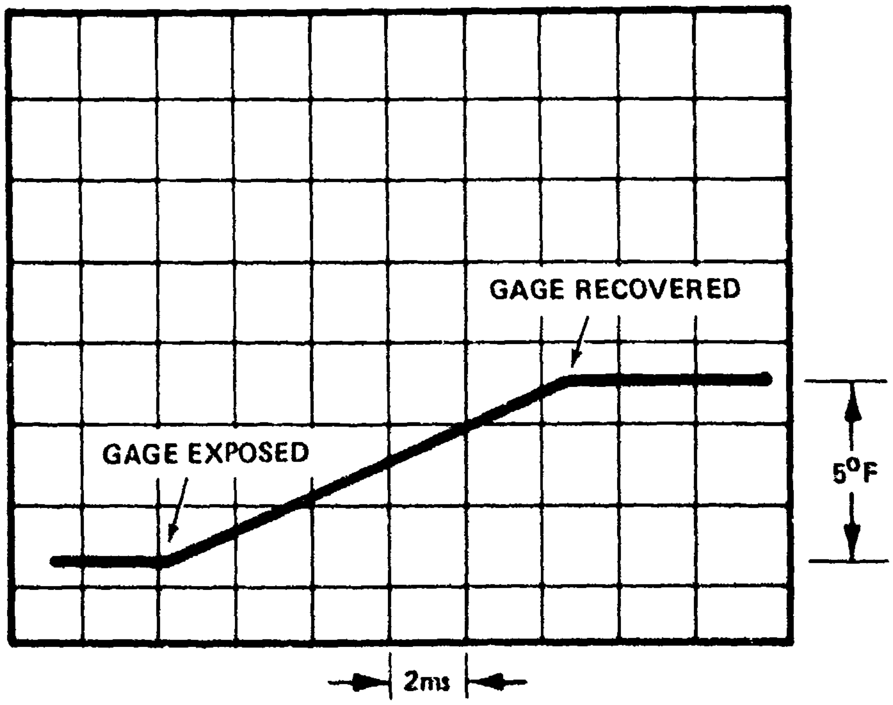


Figure 13 CALSPAN CALORIMETER GAGE



LASER HEAT FLUX CALIBRATOR



TYPICAL TEMPERATURE-TIME RECORD

Figure 14 LASER HEAT FLUX CALIBRATOR AND TYPICAL TEMPERATURE-TIME RECORD

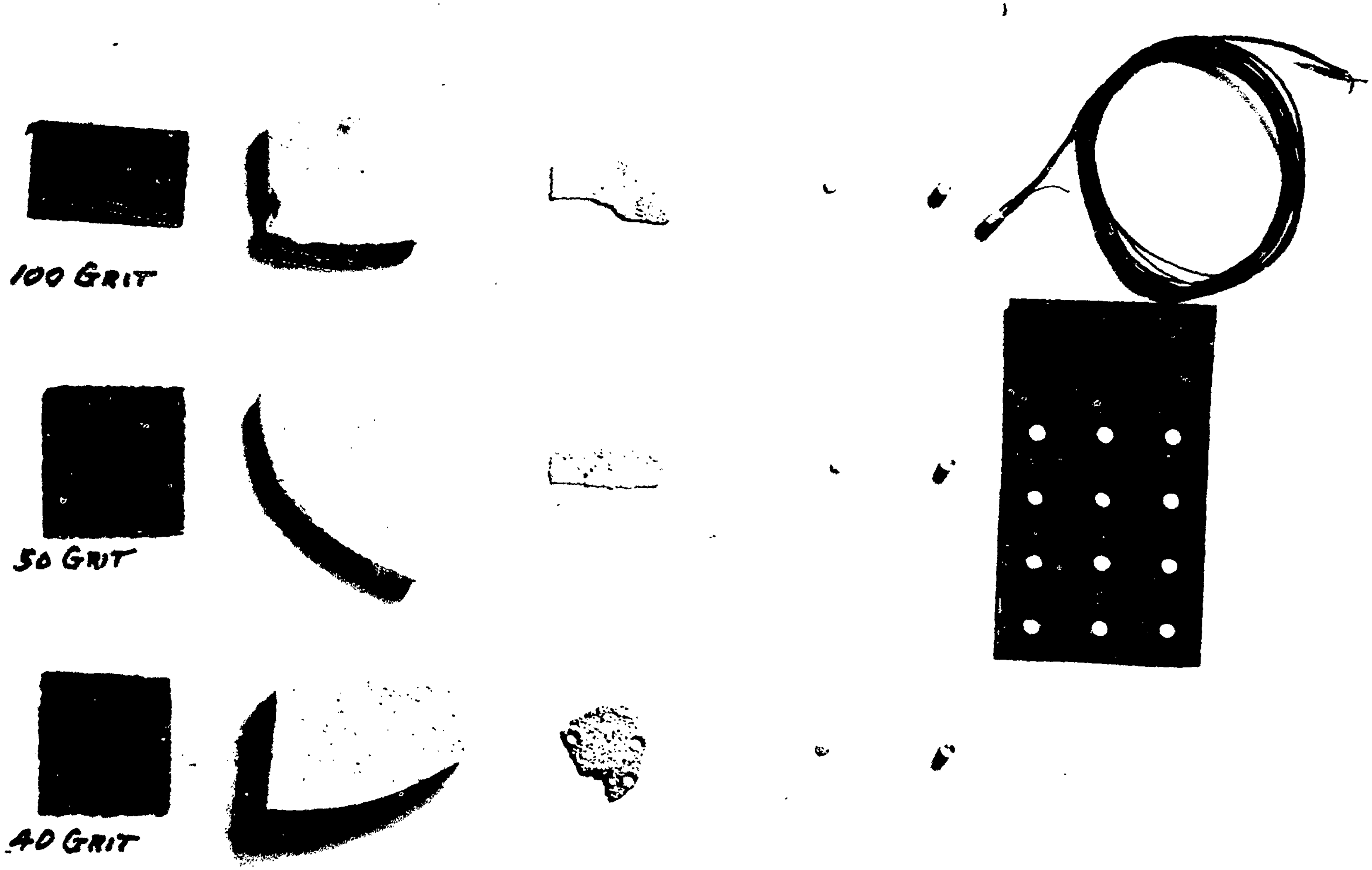


Figure 15 SEQUENCE OF CONSTRUCTION OF THE ROUGH CALORIMETER GAGES

thin-film thermometer is then added to the gage and, after the leads have been added, the unit is potted in the holder. Both types of gages are employed in our rough wall heating studies and are found to be in excellent agreement, as can be seen from the measurements on rough and smooth conical configurations shown in Figures 16 and 17, respectively. Skin friction measurements were made on both rough and smooth configurations using the Calspan-developed skin friction transducers shown in Figure 18. The roughness was bonded to the diaphragm of each transducer to form a rough surface in which the particles were packed as closely as possible without creating a multiple layer. A similar surface was molded into two types of heat transfer gages as described above.

3.2 Heat Transfer Measurements

One of the first objectives of the program was to determine whether the two different techniques (calorimeter and thin-film) used in the measurements of rough wall heating gave comparable results. Figure 19 shows a comparison between the heat transfer measurements made with the two on the windward ray of rough and smooth 6° cones at 8° incidence. It can be seen that for both sets of data, there is excellent agreement between the heat transfer measurements made with the calorimeter and thin-film gages. Note that the calorimeter has a highly thermal conductive sensing element and the thin-film gages have insulative sensing elements. We also compared our measurements made in 1978 and 1980 on the same nominal configuration: Figure 20 shows that good agreement was found between the two sets of measurements. Figures 21 through 24 show the distribution of heat transfer along the windward ray of the rough and smooth 6° cones for a series of model incidences. These measurements show that the heating enhancement resulting from roughness decreases with distances from the tip (where factors of just less than two are observed) to the base of the cone where the enhancement factor is no more than 20%. This contrasts with the predictions of Dirling,[1] Dahm[2] and Finson,[3] which give a relatively constant enhancement along the cone. We also see a significant variation in the roughness-induced skin friction augmentation along the cone which is also at variance with current prediction

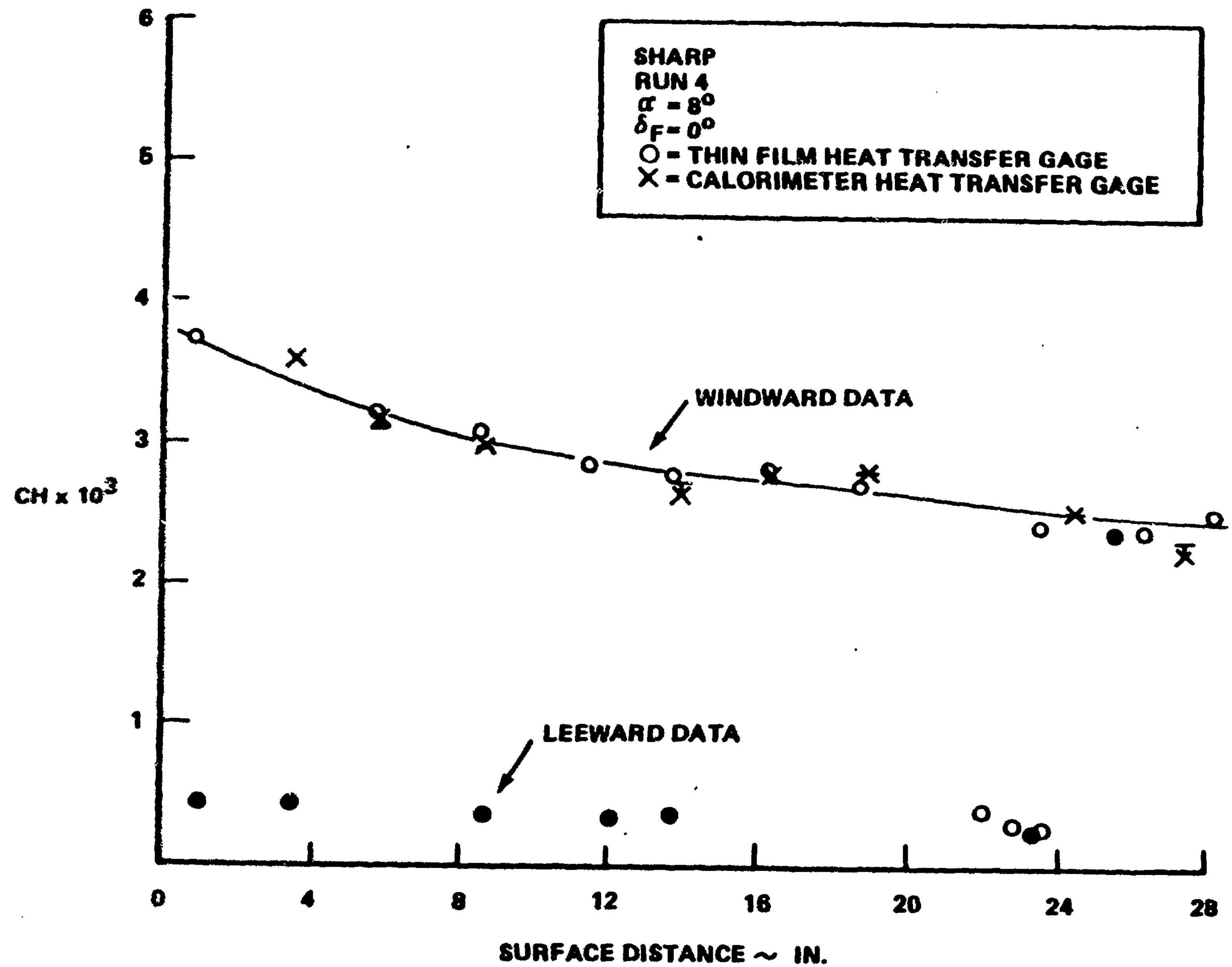


Figure 16 COMPARISON BETWEEN HEAT TRANSFER MEASUREMENT MADE WITH SMOOTH THIN FILM AND CALORIMETER HEAT TRANSFER GAGES

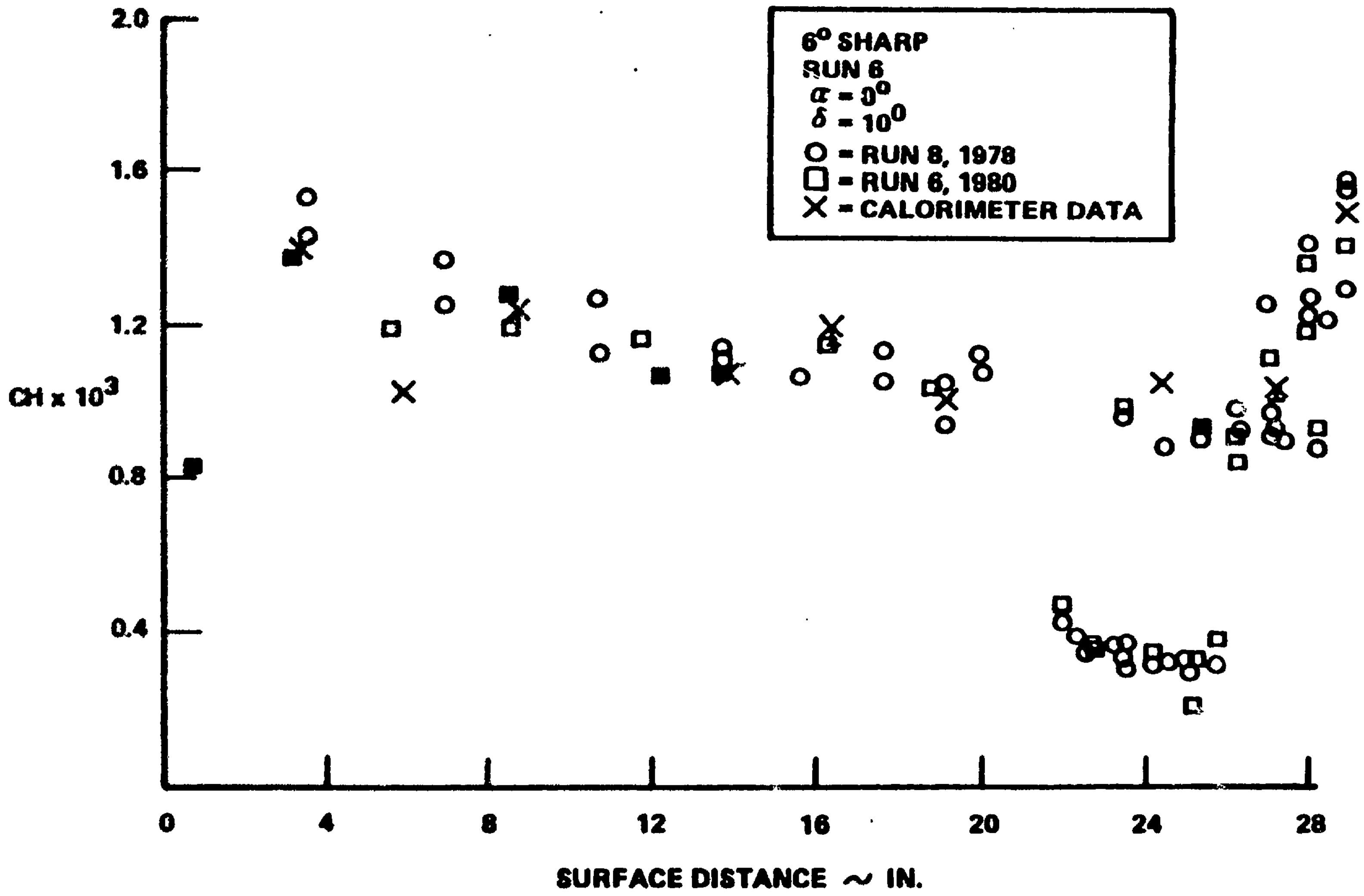


Figure 17 HEAT TRANSFER MEASUREMENT MADE IN THE 1978 AND 1980 MRV STUDIES

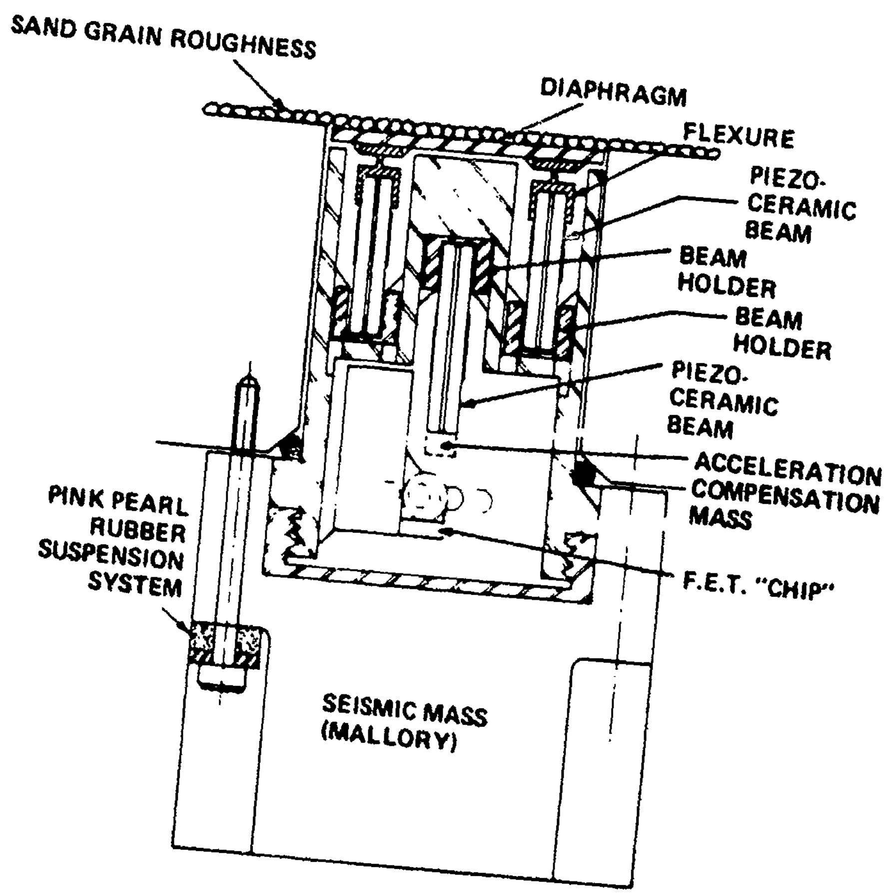


Figure 18 DRAWING OF SECTION THROUGH SKIN FRICTION TRANSDUCER

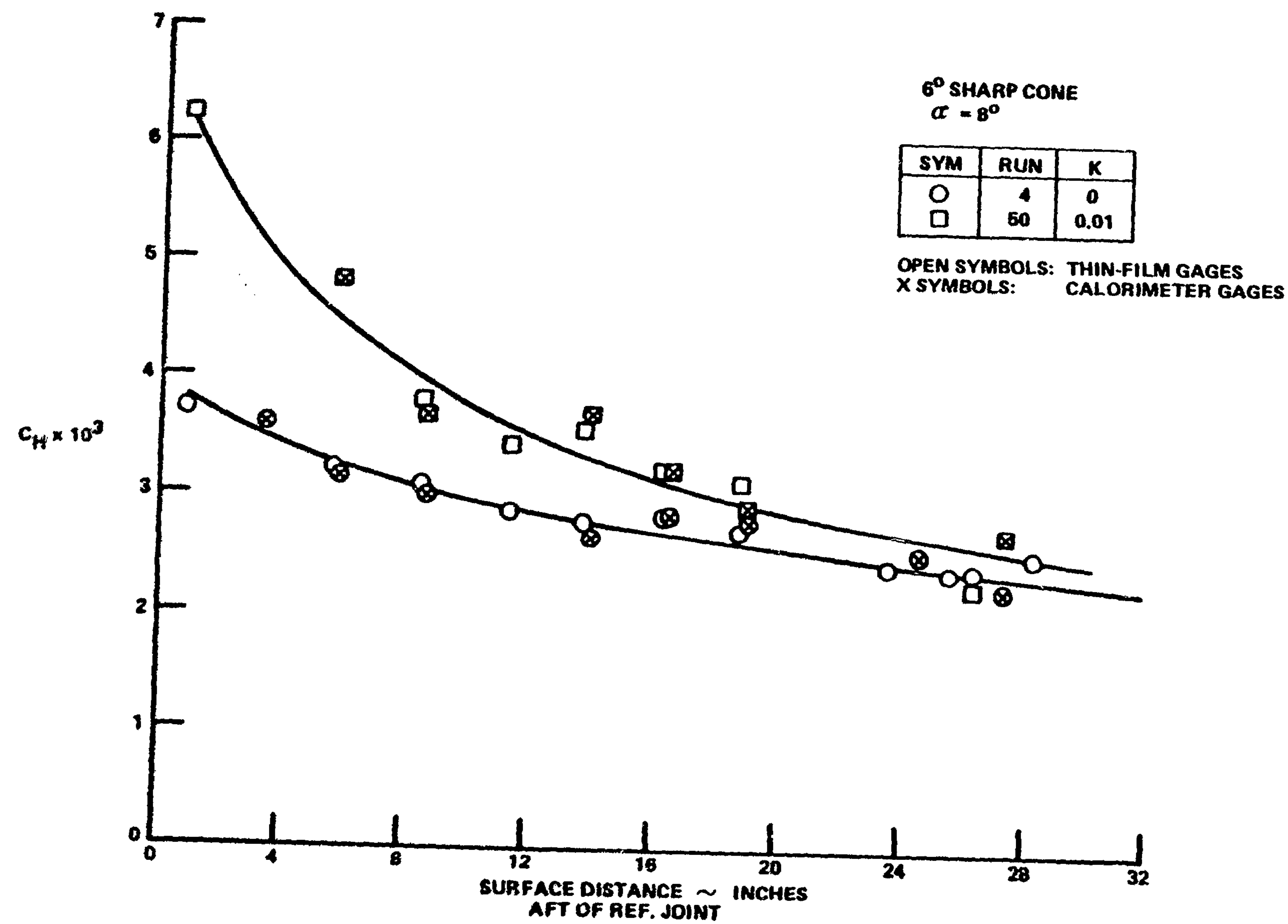


Figure 19 HEAT TRANSFER MEASUREMENT WITH CALORIMETER AND THIN FILM GAGES

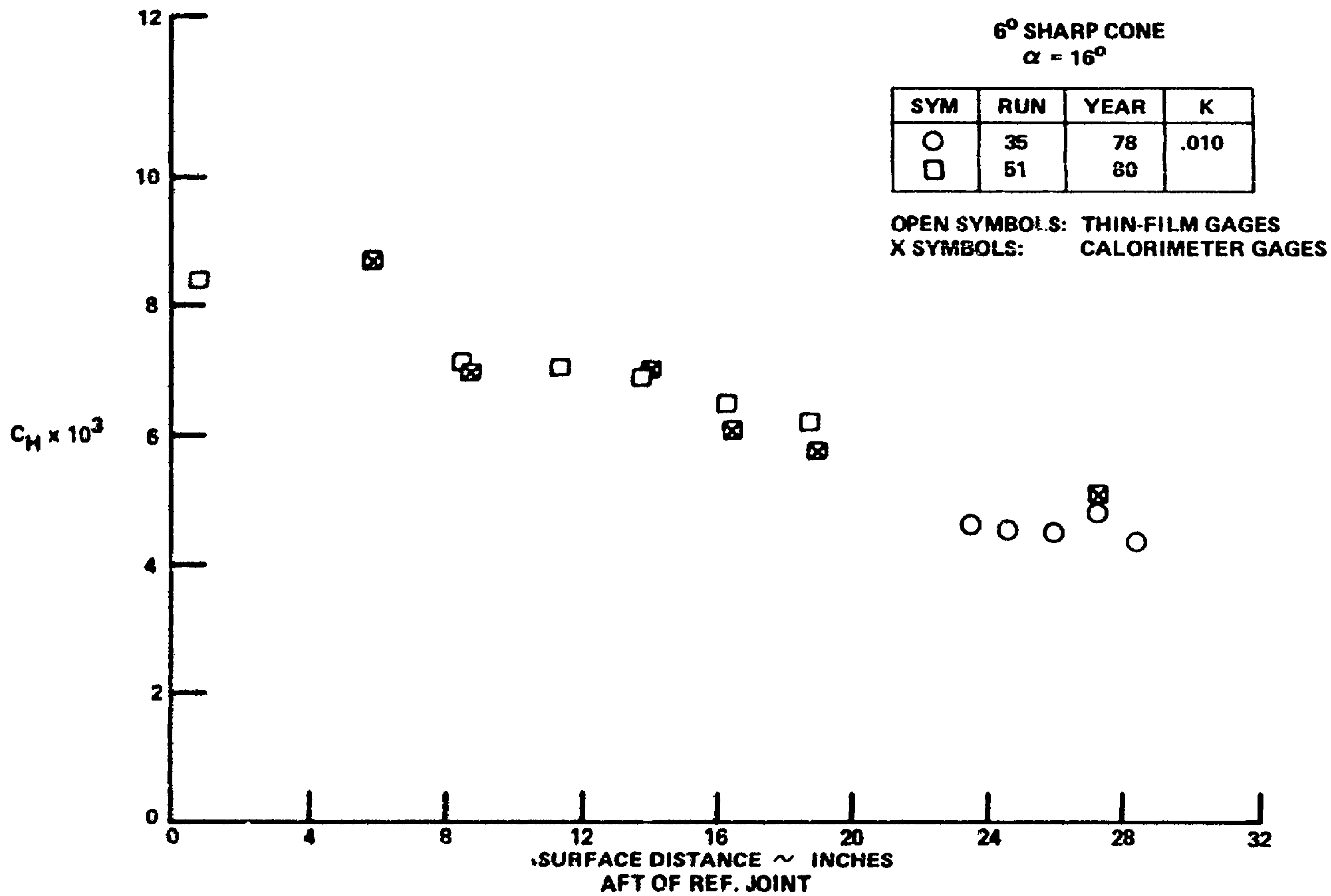


Figure 20 COMPARISON BETWEEN HEAT TRANSFER MEASUREMENTS OF HEAT TRANSFER MADE IN THE 78 AND 80 MRV STUDIES

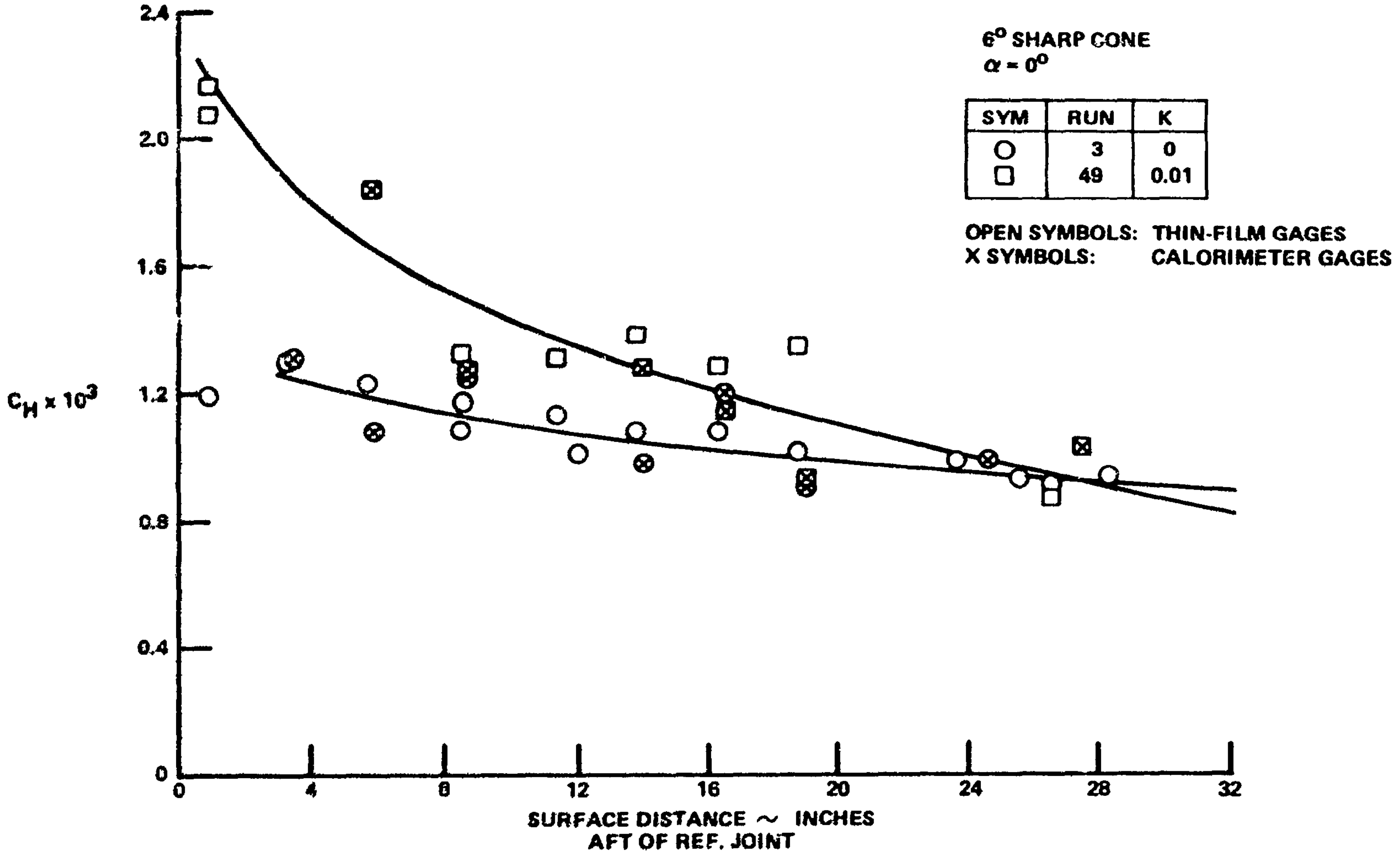


Figure 21 HEAT TRANSFER MEASUREMENTS ON THE ROUGH AND SMOOTH 6° CONE FOR $\alpha = 0$

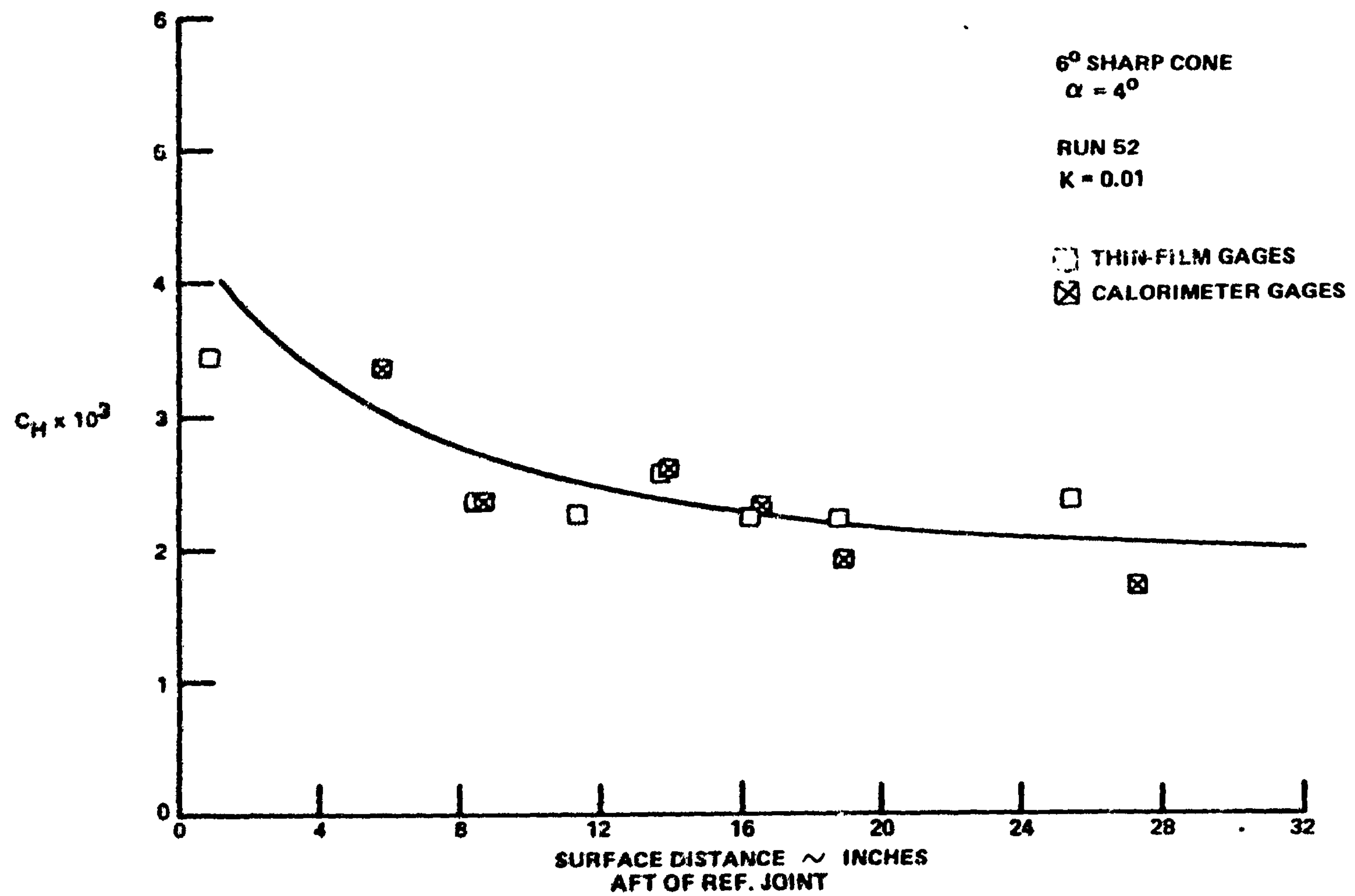


Figure 22 HEAT TRANSFER MEASUREMENTS ON THE ROUGH AND SMOOTH 6° CONE FOR α = 4

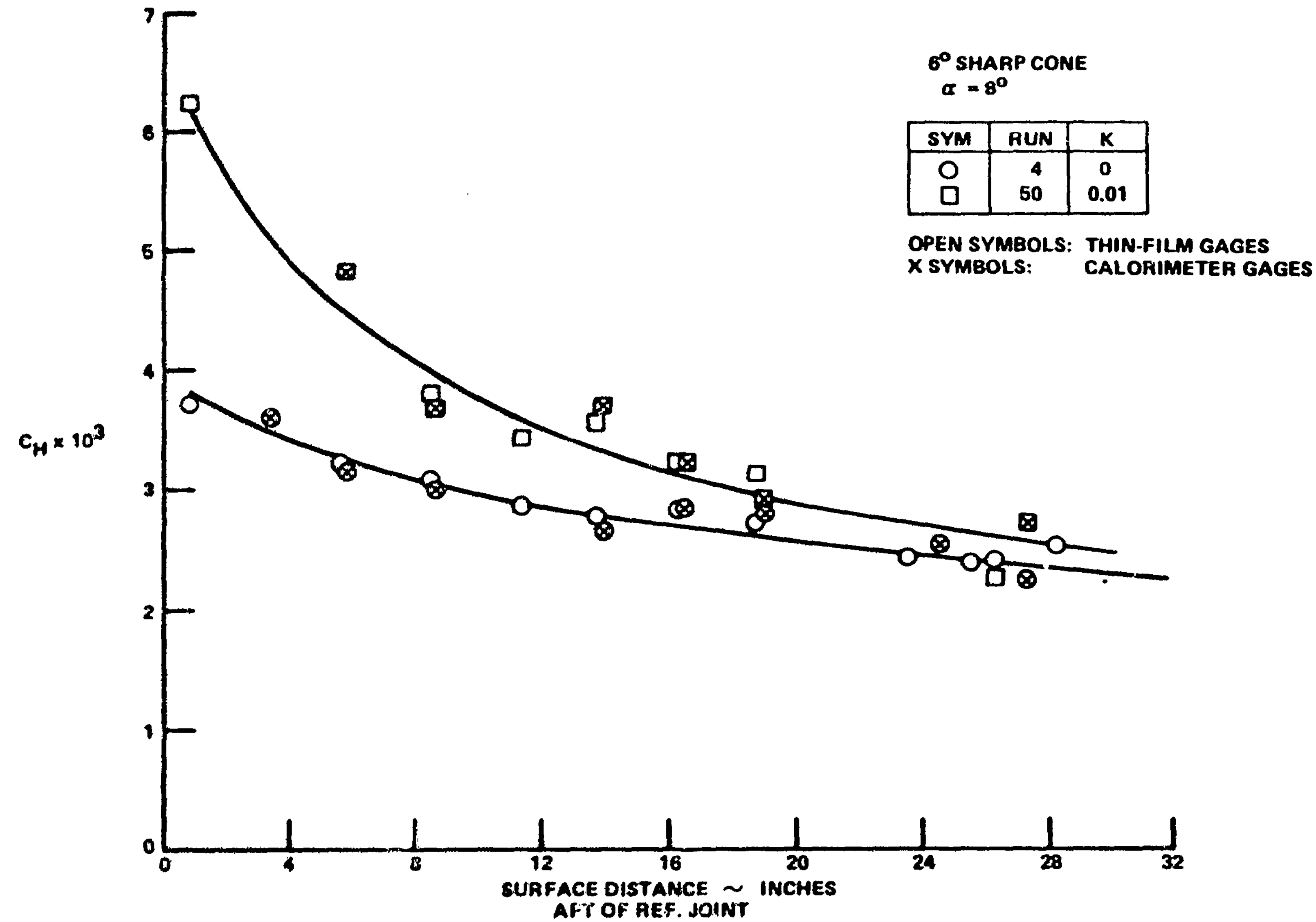


Figure 23 HEAT TRANSFER MEASUREMENTS ON THE ROUGH AND SMOOTH 6° CONE FOR α = 8°

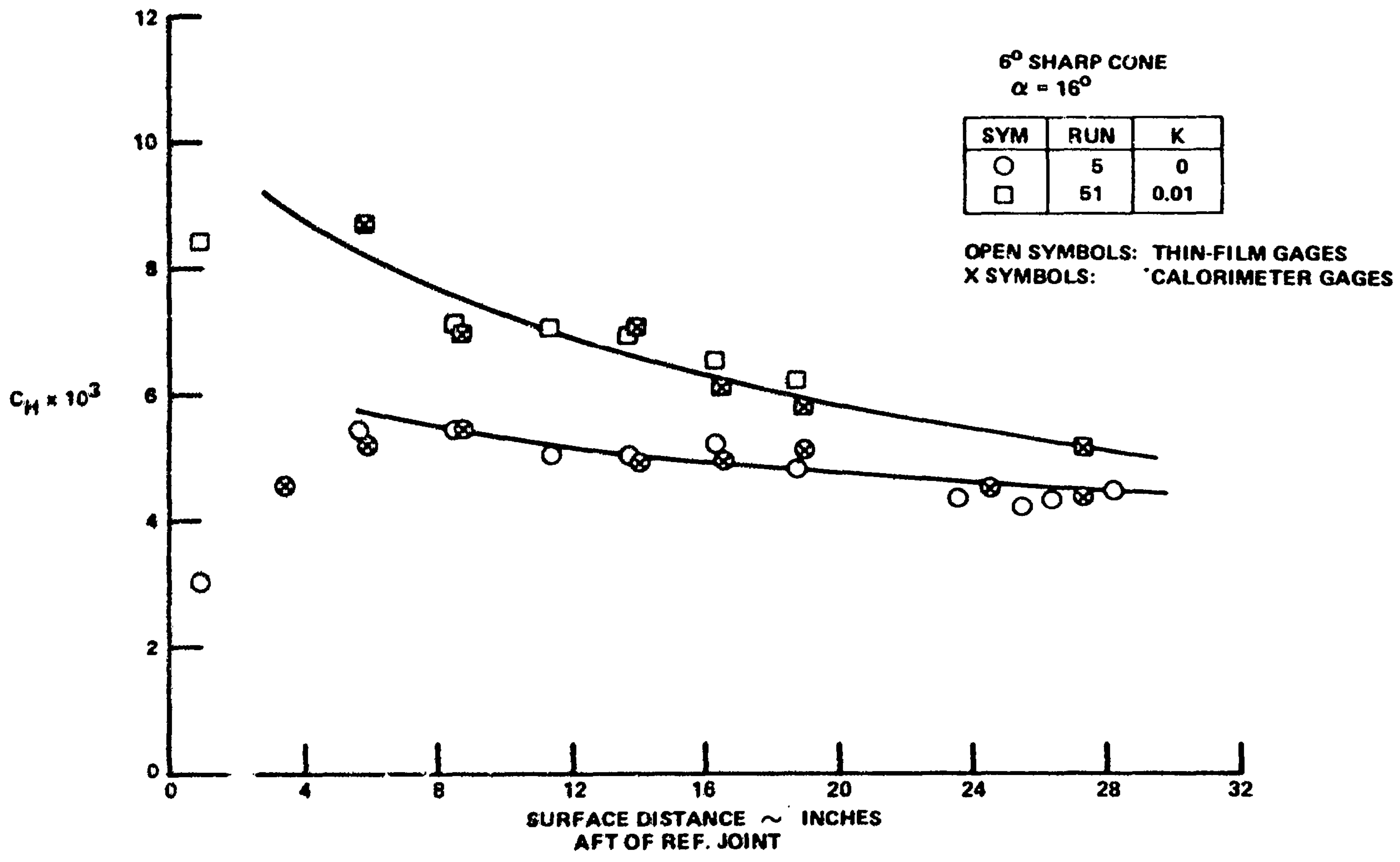


Figure 24 HEAT TRANSFER MEASUREMENTS ON THE ROUGH AND SMOOTH 6° CONE FOR α = 16°

techniques. As we observed in earlier studies on nose tip and frustum configurations, the measured Reynolds analogy factor $^{2C_H}/_{C_f}$ decreases with the roughness of the surface as shown in Figure 25. Thus, a valid prediction technique must have as its basis coupled solutions to both the momentum and energy equations.

A satisfactory explanation for the decay in roughness-augmented heating and skin friction along the cone and the variance with theory has yet to be obtained. These measurements, combined with the observations of the growth of the boundary layer, suggested that the strong initial growth of the boundary layer produced a boundary layer at the base of the cone which was thicker than if it had grown at a uniform rate. This effect could have resulted from the nonequilibrium relaxation of the turbulence in the boundary layer from a fully rough regime close to the tip to the transition regime at the base of the cone. Alternatively, as discussed earlier, a greater momentum and energy defect may be induced in the boundary layer close to the tip by roughness-induced shocks. We believe that the entropy gradients introduced in the bottom of the wall layer by this later mechanism could have a significant effect on the structure and development of a hypersonic, highly cooled turbulent boundary layer in the roughness-dominated regime. Additional experimental studies will serve to clarify these fundamental issues.

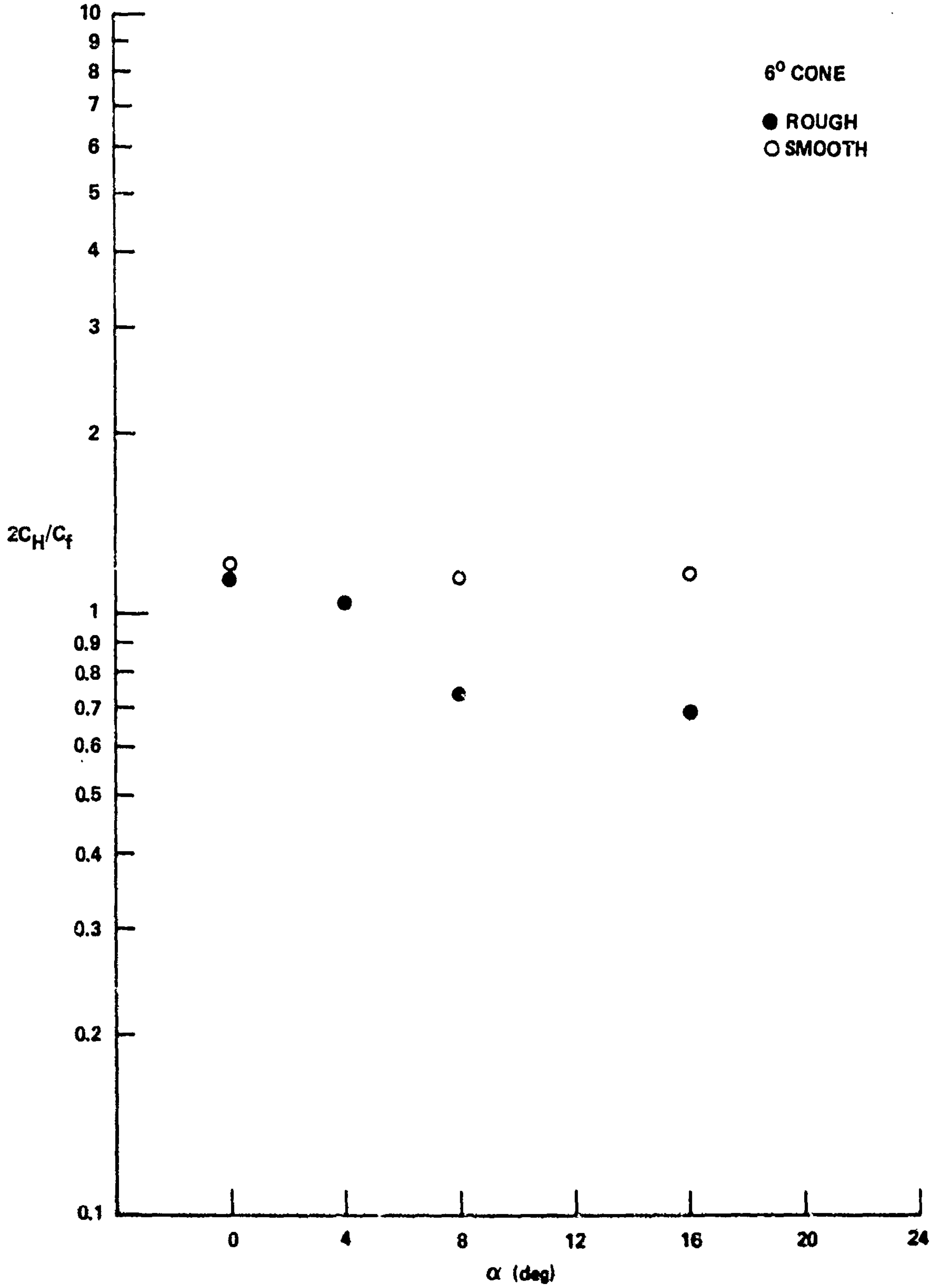


Figure 25 REYNOLDS ANALOGY FACTORS ANALYSIS FOR SMOOTH AND ROUGH CONES AT ANGLE OF ATTACK

Section 4
SUMMARY

Experimental studies are being conducted to examine the stagnation region heating in transitional flow over blunt nose tips; and the effects of surface roughness on the heat transfer and skin friction to hypersonic re-entry vehicles.

Measurements have been made of the distribution of heat transfer and skin friction over sharp and blunted cones to a range of incidences for surface roughness of 0, 10 and 15 mils. These studies have been conducted at a local Mach number of 11.7 and Reynolds numbers based on model length of 30×10^6, giving roughness Reynolds numbers from transitional to fully rough over the models. New calorimeter and thin film instrumentation was developed expressly for the rough wall heating measurements. The measurements indicated that while the roughness-induced augmentations in heat transfer and skin friction were less than would be predicted using theories based on low speed data for low R_K's, close to the nose tip significantly larger augmentation factors were observed. The current studies suggest that significant compressibility effects may be present in hypersonic turbulent boundary layers over rough walls.

The models and highly detailed heat transfer and pressure instrumentation have been completed for the stagnation point heating studies. A new and novel throat valve has been developed to eliminate the frangible mylar diaphragm which can cause particles and disturbances during flow establishment in the shock tunnel. The experimental studies are now in progress.

Section 5

REFERENCES

1. Dirling, R.B., Jr., "A Method for Computing Rough Wall Heat Transfer Rates on Reentry Nosetips", MDAC Paper WD 1778, AIAA 8th Thermophysics Conference, Palm Springs, 1973.

2. Dahm, T.J., "Analysis of AEDC Heat Transfer and Shear Data From Roughened RV Nosetip Models in Hypersonic Flow", Vol. III, Part 4, Acurex Corp. Report No. FR-80-36/AS, 1980.

3. Finson, M.L. and Wu, P.K.S., "Analysis of Roughwall Turbulent Heating With Application to Blunted Flight Vehicles", AIAA Paper No. 79-0008, 17th Aerospace Sciences Meeting, 1979.

Section 6

ACTIVITY UNDER THIS PROGRAM

The following is a list of presentations and meetings during this reporting period.

1. Holden, M.S. "Studies of Transpiration Cooling, Surface Roughness and Entropy Swallowing in Transitional and Turbulent Boundary Layer Over Nose Tips" Presented at the AIAA 15th Thermophysics Conference Snowmass, Colorado 14-16 July 1980.

2. Holden, M.S. 7/14-7/16/80 Attended short course "Transonic Viscous Interactions" at Snowmass, Colorado July 1980.

3. Holden, M.S. 10/8/80 Attended Strategic RV Systems and Gas Jet Nose Tip Conference at NASA/Langley, VA. October 1980.

4. Holden, M.S. "Studies of the Aerothermal Phenomena Affecting the Accuracy and Survivability of Ballistic Reentry Vehicles" and "Aerodynamics of Road Vehicles" Weapons Center, Silver Spring, MD. November 1979.